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FIRES AND FIRE PREVENTION IN LAKE SUPERIOR MINES[1]

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Metal-mine fires occur frequently, and are so full of possible danger to life and property that the subject of fire prevention is of continuous interest to everyone connected with mining. A review of the fire record of the Lake Superior district, noting the frequency of the fires, their causes, and the fire-prevention methods employed, should be of benefit to all. It is the purpose of this paper to consider as briefly as possible some of the fires that have occurred, their chief causes, and the fire-prevention measures and fire-fighting methods which some of the operating companies have adopted.

Changed methods of mining and fire-protection methods have in recent years effected a change in the causes and locations of underground fires. To bring this out, the fires are divided into two groups -- those before 1917, and those occurring during the period 1917-28. The earlier fires are mentioned only briefly, to emphasize the changing conditions.

Several operating companies furnished to the author as complete information as they could collect on fires in their mines. Their assistance, which makes this paper possible, is gratefully acknowledged. The list of fires given in Bureau of Mines Technical Paper 59, "Mine Fires in Lake Superior Iron Mines," by Edwin Higgins, was used to supplement information obtained on earlier fires.

EARLY FIRES OF THE LAKE SUPERIOR DISTRICT

In the following lists of fires only those caused by ignition of timber or other mining supplies are considered. The "black slate" or "sulphur" fires are treated separately further on. Forty fires occurring before 1917 are briefly summarized here.

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Summary of 40 Fires Occurring Before 1917

Place of Ignition		Probable Cause		How Fought	
Shaft	9	Candle	16	Burned Out	7
Shaft or Pump Station	13	Oil Lamps	4	Sealed	11
Shaft House	2	Carbide Lamp	1	Sealed & Water	2
Drift or Crosscut	5	Open Fire	1	Sealed & Steam	1
Sub-level	1	Oil Stove	1	Flooded	1
Stope	3	Power Torch	1	Water	11
Ore Chute	1	Sparks (surface)	3	Chemicals	2
Mule Barn	2	Electricity	2	Snow	1
Magazine	3	Lightning	1	Caved	1
Surface Cave	1	Spontaneous	1	Unknown	3
	40	Hot Ashes	1		40
		Smoking	2		
		Friction	1		
		Unknown	5		
			40		

The foregoing summary shows that formerly the shafts and the stations opening from the shafts were the danger points; 22 of the 40 fires originated in such places, and two other fires which started in wooden headworks ignited the shaft. The mule barn has been eliminated from among the other points of origin. Candles and oil-burning lamps were formerly the chief sources of ignition, and in this list they account for just half the fires; these causes have also been eliminated in our present-day mines.

The older methods of fire fighting are interesting in comparison with the more recent methods. Seven of the early fires were allowed to burn out. Eleven were sealed and allowed to smother; in most of these cases the entire mine was sealed for several days or weeks while the fire died out. According to the records, oxygen breathing apparatus was worn at only two of the fires, and chemical fire extinguishers were used at only two.

Twenty-three lives were lost in the forty fires. One of the victims was a rescue man wearing an early type of oxygen breathing apparatus. The other men were suffocated by fire gases. There is no record of any man being actually burned. Most of the men lost were in parts of the mine distant from the fire.

RECENT FIRES OF THE DISTRICT

The first group of recent fires covers the period of many changes in the Lake Superior mines. Candles and oil lamps were discarded, and carbide lamps were universally adopted; electric-trolley haulage supplanted the mules, and electricity for many purposes was introduced; fire-proofing of shafts, shaft stations, and surface structures, using steel, concrete, and "gunite", became the general practice for new construction; and fire-fighting equipment, including oxygen breathing apparatus, was rather widely installed in the district. These changes are all apparent in a study of the fires of the second group, which comprises the fires of the last 12 years - 1917-28.

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The 55 fires summarized below are those concerning which definite information was obtained. All of the serious fires are included, as well as many that were discovered and extinguished before gaining headway, but the list is known to be incomplete. A few fires that caused much damage are omitted because definite information as to cause is lacking, and many small ones are not listed because no record of them was kept. The list is large enough to show the principal causes of the fires and to allow the drawing of some conclusions about them.

Of the 55 fires, 11 caused a considerable loss of property, and seven interrupted operations in shafts. Two lives were lost. Eight other fires interrupted operations for a day or more. The other fires were discovered and extinguished before getting out of control.

Summary of 55 Fires from 1917-28

Place of Ignition		Probable Cause		How Fought	
Shaft	10	Electricity	22	Seals only	3
Shaft or pump station	6	Carbide lamps	5	Seals and water	9
Drift or crosscut	20	Paper torch	5	Seals, water and chemicals	2
Sublevel	6	Open fire	2	Seals and chemicals	3
Stope	2	Smoking	6	Seals and steam	1
Ore Chute	5	Oxyacetylene torch	2	Water	20
Ore Pocket	2	Friction	4	Chemicals	12
Raise	1	Slaked carbide	1	Ore	2
Explosives magazine	1	Spontaneous	1	Chopped out	1
Surface structures	2	Lightning	1	Flooding	1
		Unknown	6	Not given	1

Protection Used by Fire Fighters:

Oxygen breathing apparatus	21
All-Service gas masks	4
Apparatus and masks	2
None	28

Summary of Fires by Ranges and States

Range		States	
Vermillion	3	Minnesota	23
Mesabi	14	Wisconsin	3
Cuyuna	6	Michigan	29
Gogebic	16		
Minominee	2		
Marquette	6		
Copper Country	8		

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Summary of Fires by Place and Cause

Place of Origin	Electricity	Smoking	Carbide light	Torch	Friction	Other	Unknown
Shaft	4	2			4		
Stations	3					3	
Drift or crosscut	11	2	3			1	3
Stope	1			1			
Sublevel	1	2	1				2
Ore Chute				4		1	
Ore pocket						2	
Raise	1						
Magazine			1				
Shaft house	1						1
	22	6	5	5	4	7	6

Electricity predominates as a cause of fire in mines, as the foregoing summary shows. The 22 electrical fires noted have occurred since 1921 and eight of them since the first of this year, thus showing an increase coincident with the extended use of electricity underground. Since electrical fires form such an important group they will be discussed more fully than the other classes of recent fires.

In looking for the particular electrical equipment that caused ignition, it was found that fires were attributable to:

1.	Main power circuits	3
2.	Trolley or lighting circuits	10
3.	Motor feed circuits	3
4.	Signal circuits	2
5.	Other electrical equipment	4

1. Two of the main power-circuit failures were caused by caving and movement of the ground. The third fire burned all evidence of its first cause.

2. Of the trolley and lighting circuit fires, two were caused by wiring improperly installed by others than the electricians; two were caused by crushing the timber caps against the trolley; one by leaving the trolley pole on the wire at the end of the shift so that the wire was held against a timber cap; two by failure of insulators; one by a spark from the trolley wheel when passing a frog; igniting dry lagging; one from an electric light in contact with inflammable material in a closed box; and of one the cause is unknown.

3. The motor feed circuit fires were caused by crushing of the timber.

4. Both of the signal circuit fires were due to broken insulation on the signal wires.

5. One fan motor, set close to a post, heated sufficiently to ignite the wood. The motor of a sinking hoist was left running and set fire to the timber foundation. The resistance coil for an electric tugger heated and ignited

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the post on which it was hung; the controller was probably left "on" by the miner. Evidence was destroyed in the fourth case where a small transformer and resistance box burned.

Probably the most interesting of the electrical fires on record are five which were ignited by a 250-volt D.C. circuit in contact with timber.

A very unusual happening on one of the main power circuits was the parting of the connection in a junction box just enough to cause the box to heat and ignite the supporting timber. A slight ground movement placed sufficient strain on the cable to cause the parting.

Information at hand shows that six electrical fires resulted from carelessness of employees -- failure to shut off power from motors or throw sectionalizing switches, the installation of electrical wiring by unskilled men, and other violations of established rules. Improper methods of installing equipment or improper equipment resulted in three electrical fires. Failure of supposedly standard equipment caused three fires, and caving of ground caused six fires. Nine electrical fires occurred during a regular working shift and 11 of them started during an off-shift period. Most of the last group were discovered by repair crews or pumpmen.

Of the five fires started by the miners' carbide lights, three were started in old crosscuts or raises by timbermen who were hiding their tools at the end of the shift. Each of these three fires gained a considerable headway before they were discovered. Another fire of this group was started at the end of the shift, when a carbide lamp ignited a piece of canvas fan tubing. The fifth fire was started during the shift by contact of a lamp with drift timbers, and was discovered and extinguished by the mine foreman on his rounds.

Lighted paper torches thrown into ore chutes to estimate the amount of ore caused five fires which gained such headway that it was a real job to extinguish them. Oxygen breathing apparatus was used at three of these fires, which interrupted production for one or more days on account of gas.

Of the six fires caused by smoking, two occurred in shafts; one caused a considerable damage to property and closed the mine for several days, but the other was quickly discovered and extinguished. Two other fires of the six occurred in main drifts; both of these were out of control when reached and caused large damage to property. The last two fires started in sublevels, and whereas they did not cause very great property damage, both interrupted operations at the mines.

The four fires attributed to friction were all in inclined, timber-lined shafts, and were charged to overheated shaft rollers. Two of these fires resulted in large property losses.

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Two fires that should be given careful consideration were caused by oxyacetylene cutting torches. This equipment is now used underground in many places for repair work both in shafts and chutes and in ore pockets. Timber covered with metal is apt to have decayed spots that will readily ignite from the intense heat of the oxyacetylene flame, and will smoulder for a considerable time before the fire becomes really active. The smoke which naturally accompanies this kind of work may mask the wood smoke until the crew has gone. One of these fires started in an ore raise and the other in a shaft pocket; they were not discovered until some time after the repair men had finished and gone.

Another unusual fire was that started by the chemical action of moisture on calcium carbide. In this case metal cans were provided at the underground stations to receive spent carbide. As the miners emptied their lamps before going to surface, evidently much unused carbide was also dumped. Near the end of the shift about 200 pounds of this waste material was dumped into the shaft pocket and two or three cars of ore were dumped on top of it. Ignition of the timber lining resulted. Fortunately the fire was discovered before the men were all hoisted. Even though the fire was buried under the ore, it would soon have gained headway.

Lightning started a fire by striking the cables leading to the electric pump. The high voltage burnt out the control in the underground pumproom and set fire to the wooden panel and supporting timbers. The starting of fires by lightning is very unusual. One fire started spontaneously in oily waste placed behind a wooden post in a timbered pumproom. Two fires started from small open fires, one for warming a pumproom and the other for heating waterproofing paint.

FIRE PREVENTION AT THE MINES

Much good work in fire prevention has been done by some of the companies, but it can only be outlined here. The fire-prevention work has resulted in a smaller number of fires in shafts and shaft stations, in a decrease in the percentage of serious fires, and, perhaps the most striking result of all, in a marked decrease in loss of life.

FIREPROOFING

Some of the factors involved in fireproofing a mine are:

1. The use of steel sets -- steel sets with concrete lath and reenforced concrete for shaft construction.

2. The installation of sprinkling systems in timbered shafts.

3. The use of gunite to fireproof shaft timber.

4. The use of steel, concrete, and gunite in shaft and pump stations and in explosives magazines.

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5. The installation of steel sets in drifts as fire breaks, or the removal of timber and guniting of sections of rock drift.

6. Experiments with fire retarding timber preservatives for drift timbers.

7. Installation of special water lines for fire fighting in drifts and sublevels; placing special fire hydrants or regular drilling lines; interconnecting water and air-pipe lines; installing a special series of water tanks at shafts stations in deep mines to regulate pressure; providing adequate fire hose at underground stations.

8. General use of soda-acid and carbon-tetrachloride fire extinguishers at surface and underground stations.

9. The installation of special fire doors to sectionalize the mine.

10. The use of covered metal containers for oily waste, spent carbide, litter from explosives magazines, and other small inflammable materials.

11. Limiting supplies of oil, etc., underground.

12. Keeping the entire mine free from accumulations of rubbish, especially the magazines and stations.

13. Maintaining fire patrols in the mine between working shifts.

14. Adopting very rigid specifications for electrical supplies and installations.

15. Prohibiting or limiting smoking underground.

16. Providing a quick method of fire warning by stenches and mine telephones.

17. Maintaining mine-rescue stations and trained men.

18. Making special studies of fire hazards and having prearranged plans for emergencies, with definite organization, outlined instructions, and fire maps.

The foregoing list briefly covers the fire-prevention work upon which a great deal of thought and money have been expended. Some mines still have done very little toward fire prevention, but others have done everything listed above, and more. Fires that occurred in mines that were fully prepared for prevention have been extinguished with little loss of property and small risk to the fire fighters. Time does not permit a detailed discussion of all these preventive measures, but a few will be enlarged upon.

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Disposal of Rubbish

The boxes, paper, and sawdust that go into the mines with blasting supplies constitute the largest source of very inflammable waste material that must be disposed of. Investigation shows that most of the mines hoist the sawdust and paper and dispose of it on the surface. About 75 per cent of the mines also hoist all explosives boxes and fuse cases shortly after they are emptied. Some of the top-slice mines break up the boxes, make the pieces into bundles, and place them in a room just before blasting; they thus become a part of the mat. In a few mines the boxes are left underground, where they are subject to ignition.

Metal containers are commonly used for oily rags and waste and for fine refuse from the magazines. Some companies provide metal cans at the shaft stations for spent carbide and for all small litter, so that there is no chance for such material to accumulate underground. Less attention is paid to the bark and chips that accumulate at the timber raises where piles of considerable size may often be found. Old timber from repair work is generally hoisted or placed in the mat; occasionally it is piled in unused crosscuts to decay and become a fire hazard.

Fire Doors

For the cost involved, a good system of fire doors is probably more protection to life and property than any other device. All main shafts at every level and all definite sections of the mine should be provided with doors so that they can be quickly shut off from the rest of the mine.

When there is a serious hazard to a shaft, the doors can be mechanically closed from the surface or various underground points. The Lake Superior district has fire doors of many types and of varied construction. There are concrete frames with steel doors, wooden doors protected with metal or gunite, and doors of unprotected wood. Although the fireproof construction is the most desirable, wooden doors will do good service until the fire reaches them.

Mine-Rescue Stations

With one notable exception, each mining district in the Lake Superior region is well provided with special mine-rescue apparatus and trained men. The various mining companies maintain in their mine-rescue stations 220 sets of two-hour type oxygen breathing apparatus and 65 All-Service gas masks. Bureau of Mines Car No. 8 carries 16 sets of oxygen breathing apparatus and 5 All-Service masks. In addition to these masks, some companies have gas masks that are not considered as part of the mine-rescue equipment, and most of the local fire departments have equipment that is available in emergencies, so that the total number of masks is well above 300 sets. The company-owned apparatus is located as follows:

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	Sets
Vermillion Range	20
Mesabi Range	50
Cuyuna Range	--
Gogebic Range	65
Menominee Range	54
Marquette Range	35
Copper Country	61
Total	285

Most of the large companies and a few of the smaller ones maintain mine-rescue stations, employ their own instructor who carries on the training work regularly and have a regular crew of trained men. A few companies are still wholly dependent upon their neighbors in case of fire. Also some mines are dependent upon their own company stations which are located at a considerable distance.

The mine-rescue telephone, for use in fighting underground fires, was developed in the district and has been adopted by three companies as regular fire fighting equipment. It has been used at three fires and each time has simplified and made safer the work of the apparatus men.

The Lake Superior mines were among the pioneers in the use of oxygen breathing apparatus; the first equipment was purchased in 1911. As improved equipment has been devised it has been adopted, so that the rescue stations contain modern types of apparatus, All-Service masks, self-rescuer masks, the latest gas-detecting device, and supplies that have been proved of value in mine-fire work.

Mine-Rescue Training

Training in the wearing of oxygen-breathing apparatus and All-Service masks and in the rudiments of mine-fire fighting is still generally called "rescue training," as the possible saving of life is its first consideration. Mining companies take much interest in training work. It is believed that there is not an underground mine in the district without men trained in the use of breathing apparatus. Twenty-five company employees spend a part of their time keeping the equipment in shape and carrying on the training of the men. The Bureau of Mines instructors are kept busy with requests for training; they reach each mine in the district every second year. The exact number of men who have received training is not known. Over one thousand men have been trained in this work by the Bureau of Mines during the last three years, but they are only a part of the trained men in the district. The men are taught the construction and functioning of the oxygen breathing apparatus, All-Service mask, and "self-rescuer" type of carbon monoxide mask, are required to wear the protective devices in smoke and gas until they have confidence in them, are given instruction in the effects of fire gases, and are taken underground and taught the elements of mine-fire fighting. They are taught, especially, the limitations of the different types of protection, and how to take care of themselves and their team-mates in any emergency. Every rescue man knows how to administer artificial respiration.

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As a result of the rescue training, men wore respiratory protection at 27 of the recent fires, and there were no serious accidents. In a few cases work was done in atmospheres that would have been quickly fatal to unprotected men and at great distances from fresh air.

Many of the operating officials and engineers are qualified mine-rescue men and have also taken the special course in fire-fighting work given by the Bureau of Mines, which teaches organization and procedure, gas sampling and analysis, control of ventilation, and other details of fire fighting.

Results of Fire-Prevention Work

With changes in the causes of ignition it is difficult to estimate just what effect the fire-prevention work has had on the number of ignitions. Taken at their face value, the figures given in the two summaries of fires show that fireproofing work done in the shafts and in the shaft and pump stations has prevented a number of fires. Nine of the earlier fires, or 23 per cent, started in shafts, and 13, or 32 per cent, in shaft or pump stations -- a total of 22 out of 40 fires, or 55 per cent, that started in such places. Attention to fireproofing and protecting these exposures started during the first period; the work is far from completed now, since 16 of the late fires had their beginnings in shaft or station. Ten fires out of 55, or 18 per cent, started in the shafts, and six, or 11 per cent, in shaft or pump stations -- a total of 16, or 29 per cent; this class of fires has been reduced almost one-half according to these figures. The reduction of fires starting in underground stations is particularly notable, and can be attributed both to fireproofing and to the care and removal of rubbish.

Property loss and probable loss of life certainly have been prevented by fire-fighting equipment and trained men. One-half of the earlier fires were either allowed to burn out or the mine was sealed to smother them and no further work done. Other fires were fought at great risk to the men. At only two of these earlier fires was oxygen breathing apparatus used. Twenty-seven of the recent fires were fought by men wearing apparatus or masks. The increased use of chemical fire extinguishers is also very marked; 12 fires were extinguished by them alone; they were used five times in conjunction with other methods. The use of brattices or bulkheads to seal off fires has not decreased, but the method of use has changed. If the fire is beyond direct fighting, the tendency is to employ temporary seals to isolate a small part of the mine and thus smother the fire, rather than to seal the entire mine. This procedure greatly simplifies the work and reduces the property loss. Fire and ventilation doors, where installed, speed up the work of sealing. At several fires mechanical ventilation under control greatly helped the fire fighters. Much of this work would be impossible without trained crews equipped to fight fires in gas and smoke. Without doubt many recent fires which resulted in insignificant losses would quickly have reached the disaster class had they started 20 years ago. Where some vital part of the fire protection had been neglected, some of the recent fires caused a considerable property loss.

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The employment of fire-patrol men in the Lake Superior district is limited to a few companies, and has only recently been taken up. Three of the fires listed in the summary were discovered and extinguished by patrol-men. That such men could be employed to advantage at more properties is indicated by the fact that 29 out of the 55 fires either started or gained headway between regular working shifts. Many of the fires were detected by pumpmen or repair crews working in a distant part of the mine or by men on the surface; some were discovered only when the next shift went to work. A few of the fires had become serious before they were reached.

SPECIAL DANGERS

The great danger to life in most metal-mine fires is from fire gases -- particularly from carbon monoxide. There is always danger that workmen will be trapped by gas before they can be warned. Very few men have been injured directly by the fire, but carbon monoxide has caused the loss of many lives in remote parts of the mine. Where the ventilation is natural it is almost impossible to predict the course of the fire gases, and changes due to the progress of the fire or to local caves may occur at any minute.

To minimize danger there should be methods of quickly warning everyone in the mine; fire doors that divide the mine into as small sections as feasible should be installed; a plainly-marked second exit should be provided; and, in particularly hazardous places, a supply of self-rescuer type masks to protect the men while coming out should be available. Mechanical ventilation under control is of the greatest benefit in both rescue and fire-fighting work; where it is not used, crews unprotected by oxygen-breathing apparatus or All-Service gas masks should work cautiously, lest they be cut off from fresh air by an inflow of gas behind them.

FORMATION OF CARBON MONOXIDE

Carbon monoxide is usually defined as a product of incomplete combustion, since it is a combination of one atom each of carbon and oxygen. Much of the literature gives the impression that CO is formed mainly after a fire is sealed and deprived of the oxygen necessary for combustion. This is not necessarily true. The following facts on the formation of this gas are taken from a review of many articles:

CO may be distilled from wood by heat below the ignition temperature.

CO in dangerous quantities is produced by slow smouldering fires.

Normally, the hotter the fire the greater is the percentage of CO in the gases. CO has been formed so rapidly under such a condition that men have been overcome almost instantly in their working places.

Timber is approximately 50 per cent carbon, and this carbon is the source of most of the CO and CO_2 in the fire gases in metal mines. Computations of the ratio between these two gases produced by burning pure carbon at different temperatures were made by D. W. Rees (Coal Age, December, 1926). The results as shown in the graph accompanying his article are approximately:

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Temperature, °F.	Parts CO_2	Parts CO
800	100	1
900	25	1
1,000	10	1
1,200	1	1
1,400	1	10

It can readily be seen that a hot, quick-burning fire is much more dangerous than a slower one. The higher the temperatures, also, the greater the expansion of the gases, and the more rapidly they will fill the mine workings.

All kinds of timber in the same physical state will ignite at about the same temperature. Experiments showed that on exposure to a temperature of 375°C. (657°F.), all specimens ignited in less than two minutes. The heat of an acetylene flame is given as 1,871°C. (3,400°F.), which is more than sufficient for essentially instant ignition. Quick-burning fires, especially in shafts or raises, produce intense heat. In one fire area that had been sealed, temperatures of 1,200° F. were recorded. At another place, copper ore was smelted.

The possibility of high carbon monoxide from a fire has been shown, but actual samples taken of the return air are usually below 1 per cent CO, and the writer has never found it above that figure at an unsealed metal-mine fire.

When a fire is first sealed, the oxygen content in the sealed area rapidly drops, and there is a rise in both CO and CO_2. Deprived of its oxygen, the fire slowly dies. Active combustion stops at about 16 per cent oxygen, and standing timber quickly cools below the ignition temperature. Timber that is buried under caves or piles of decaying timber, where the heat is not readily dissipated, will smoulder in air with a much lower O_2 content, ready to flare up on the admission of fresh air. As long as there is combustion, CO will form, and probably will continue to form in small quantities after active burning ceases, but as the fire cools, the CO decreases in concentration. Although it is not known just when or how this gas disappears, it is safe to say that as long as traces of CO are present behind fire seals, there is danger of a "flare-up" if air is admitted. The presence of CO has been used as an indicator of an active fire; experience has shown that this is a good danger signal.

BLACK SLATE OR SULPHUR FIRES

The occurrence of carbonaceous slate gives rise to a troublesome condition in a number of mines on the Menominee Range. The slate is structurally weak, apt to cave when exposed, and carries much finely-divided pyrite. When the slate is either crushed in place or caved into old workings, the air is admitted to a multitude of the small particles of pyrite. Oxidation goes on rather rapidly, and as the conditions are such that the heat of oxidation can not be dissipated, it finally reaches a temperature great enough to cause ignition of the pyrite and of the carbon of the slate. The resulting fires produce large quantities of SO_2 from the pyrite, and of CO and CO_2 from the carbon in the slate. On account of their location in old workings, these fires must usually be sealed tightly and kept sealed indefinitely. With

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the admission of air, as long as there is exposed pyrite to oxidize, there will be a quick recurrence of fire. There is need for further study of these fires, especially of the gases produced by them. There is a possibility that small quantities of H_2S may be formed under certain conditions, as its characteristic order has been reported. The main thing noticed is the very low oxygen content behind the seals, making the use of oxygen breathing apparatus absolutely necessary if exploration or other work of any kind is to be done there.

In the prevention of these fires two things have been done successfully -- a protecting layer of ore has been left over the slate, and the stopes have been filled when completed. Filling of ignited stopes is also being tried. These measures have been successful, but their application to other mines is an economic problem. At least eight mines have experienced one or more of these fires. In each case the fires were bulkheaded by men in apparatus.

METHANE EXPLOSIONS

The occurrence of explosive gases in metal mines is rare enough to put the miners off their guard, but frequent enough to cause a number of accidents. In some metal mining districts, pockets of methane (CH_4) are found in carbonaceous formations. No gas-producing strata is known in the Lake Superior district. There have been a few fatal explosions of methane and a number of occurrences of it during the unwatering of old mines. There are two possible sources of methane common to the district which should be carefully considered when reopening a mine. The first is the decay of the mine timber in the absence of oxygen; this is probably the source of most of the occurrences. The other is the chance that waters coming into the workings through swamps or muskegs will trap the "marsh gas," or methane which is formed from the decaying vegetable matter in the swamp, and release it in the old workings.

The probability of finding methane is of sufficient importance to make necessary the careful and continuous testing of the air during unwatering and exploration. There are three appliances now approved for such testing; the flame safety lamp, the Burrell Methane Indicator, and the Martiensson Methane Indicator. Testing for explosive gases is part of the instruction given by the Bureau of Mines in its advanced fire-fighting course, and Car No. 8 is equipped with testing apparatus.

When methane is even suspected, all sources of ignition, such as open lights, open flame of any type such for instance as a lighted match, and sources of electrical arcs should be kept out of the mine until the air has been tested.

SPONTANEOUS IGNITIONS

Since burning is merely the rapid combination of atmospheric oxygen and the carbon, or other element, it is possible for a fire to start without the application of flame or external heat, merely through the rapid combination of these elements. Such fires are not common and can be guarded against. Two conditions are necessary: First, the opportunity for rapid oxidation; second, the retaining of the heat of oxidation. The materials which most readily oxidize are oils, greases, and the volatile hydrocarbons. Of this class of materials, oily waste or

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rags, sawdust, or other finely-divided wood, are the most commonly found. If oily waste is so confined that heat from the oxidation of the oils can not be dissipated rapidly, spontaneous combustion is probable. The one recent fire in the district from spontaneous combustion originated in some oily waste that had been forced behind a post in a poorly ventilated pumproom.

Wood alternately wet and dried absorbs a much greater quantity of oxygen than it normally contains, and attains a condition where it is much more readily ignited than if kept either wet or dry. The more finely divided the wood is, the greater is the danger from this source. Such material does not have to be subjected to a high temperature to cause it to blaze; at just the proper stage, the sudden admission of air may cause sufficiently rapid oxidation to fire the mass. This is of importance where sawdust is used to pack steam lines.

Bacterial action in moist wood that is deprived of proper ventilation may create enough heat through fermentation to gradually char the wood. If oxygen in sufficient quantities is admitted, the mass may be raised to the point of ignition; this applies to sawdust or finely divided wood in old mine workings. The greatest danger from gob fires is found where human or animal excreta is present. Through the decomposition of this matter phosphorous compounds such as phospheretted hydrogen are formed and ignite upon contact with the air.

There is no record of a fire having started spontaneously in the caved top-slice rooms of the district. The highest temperatures that have been found in accessible spots are much below the danger zone. Nevertheless, it is only a reasonable precaution to exclude from the timber mat all materials that will increase the fire hazard.

FIRE-FIGHTING PLANS

Important steps in protecting a mine are to study it carefully, to face hazards honestly, and to formulate the best possible plans for meeting all emergencies. Such study may lead to the elimination of many dangerous conditions; it will show where fire protection is needed in the way of water, chemical extinguishers, and fire doors. Mapping of the regular air currents will help in planning the safe removal of men and the attack on the fire. Knowledge of the ventilation will also make possible the formulating of plans to be carried out on the discovery of a fire, the closing or opening of doors, and manipulation of fans, may save both life and property and greatly aid in fighting the fire. The first hour of a fire is the critical time, but there have been many mine fires where nothing was done until several hours had been consumed in confused planning. There are always many decisions that must be made for each fire. Where there is a general plan carefully thought out beforehand, these decisions can receive the undivided attention of the men in charge.

The tendency of many local mine officials to minimize the danger of underground fires is to be regretted. Their indifference causes them to neglect the making of fire plans, and also has an unfortunate effect upon the attitude of the

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men. If the miners are led to believe that the mine is "fireproof" they will have little incentive to be careful in smoking or in the use of open lights. The bosses should frankly explain the dangers of the particular mine to the miners when instructing them as to the various exits to the surface, and should try to obtain their cooperation in preventing fire.

The need of previous organization and planning can only be mentioned here. A number of good papers have been written on the subject. One which covers it concisely and which is especially applicable to the Lake Superior district is "Fire Prevention and Fire Fighting in Metal Mines," by Eaton and Connibear. This paper can be found in the Proceedings of the Lake Superior Mining Institute for 1923 and is recommended to all who have not studied it.

FIRE-RESISTANT TIMBER

Experiments in making mining timber fire-resisting where steel, concrete, or masonry construction is not practical have proceeded along two lines. Coating timbers with gunite has been tried out extensively. The coating of cement makes the ignition of the timber from a local source of heat almost impossible, but experience has proved that it will not prevent the burning of the timber if subjected to a constant high heat. A recent fire started in an unprotected part of a shaft, below gunited timbers. The bare timbers were entirely burned out. The gunited timbers were burned to some extent for 300 feet above their lower limit, but the cement undoubtedly checked the fire. Only one or two sets of gunited station timbers nearest the shaft burned. The main objection that has been made to gunite is that the timber decays beneath it unobserved. Gunite is used quite extensively in the Lake Superior mines.

The treatment of timber with fire-resisting chemicals has been advocated, but the practice has been little used in the mines of the Lake Superior district. The burning of timber takes place in two ways: Volatile, combustible gases are driven off by the heat and burn, then the nonvolatile parts, such as charcoal, burn. To reduce the tendency to burn, three classes of chemicals can be used: Chemicals which are sublimated and give off noninflammable gases when heated and so dilute the inflammable ones; chemicals which lose their water of crystallization when heated and give off noninflammable gases; and chemicals which melt upon heating and form a nonburning protective coating in the wood. Laboratory tests of many chemicals have been made, so that their characteristics are known. None has been found which renders wood incapable of burning, but there are several that can be forced into timber so as to make it difficult to fire and much slower to burn. One of these, borax, has good fire-retarding properties and is an efficient fungicide, so that timbers treated with it are both fire and decay resistant. Experimental timbers treated with the different chemicals have been placed in the Athens Mine near Ishpeming, Mich. for service tests. If the timbers prove satisfactory, the use of the chemicals for treating mining timbers should become general.

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RECENT FIRES IN OTHER DISTRICTS

Within the past six months there have been three metal-mine fires which caused heavy losses in lives and property. Two of the mines were not provided with mine-rescue equipment or men trained in the use of oxygen breathing apparatus. At the third mine there was only enough equipment for one crew. Much valuable time was lost because no previous organization scheme had been thought out beforehand. In each case the fire hazard had been greatly underestimated by the men in charge. The habit of failing to recognize the serious possibilities of familiar conditions in the mine is too common in all metal-mining districts. The fireproof mine is a rare exception -- in fact, is almost nonexistent.

The results of the study of mine fires in various parts of the country can be found in the following Bureau of Mines publications: Bulletin 188, Lessons from the Granite Mountain Fire; Technical Paper 24, Mine Fires, a Preliminary Study; Technical Paper 314, Metal-Mine Fires; and Bulletin 229, Fifty-Nine Coal-Mine Fires.

RESULTS OF MINE FIRES

The results of mine fire are often more serious than appear at a casual glance. The direct costs of fighting the fire and reclaiming the mine are high. Once a fire gets beyond direct control, the expense mounts rapidly. Such a fire in a drift seldom costs less than $10,000 and frequently exceeds $50,000. Fires in timbered shafts cost more and are more apt to disrupt production for long periods; they seldom cost less than $50,000, and a few have reached the million-dollar class. Even though there is no loss of life, the expense of reopening the burned area is a serious thing for the company. The employees and the community suffer generally through the enforced unemployment of a large part of the men.

Serious loss of life at mine fires always results in undesirable publicity, political investigations, and attempts at regulatory laws, and strained relations with the workmen, affecting not only the mine which suffers the loss, but the entire industry in the section and state. For these reasons every effort should be made to promote among both mine operators and miners a sentiment that would deter any company from operating under conditions permitting of disaster.

SUMMARY

The circumstances attending fires which have recently occurred compel the conclusion that the mines of the district contain serious fire hazards. However, much good fire-prevention work has been done, the results of which are seen in the decrease in fires in shafts and stations through fireproofing. The tendency in new construction is toward fireproof structures. Some mines have done practically all that is possible in the way of providing fire-fighting equipment, trained men, building fire doors, installing stench warnings, keeping the mine clean, and formulating fire-fighting plans. The protected class of mines is becoming larger each year, but there are still a few which are unprotected and have grave fire hazards.

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The results obtained by the trained fire-fighting crews called upon to use oxygen breathing apparatus have been very gratifying and have greatly reduced property losses. The district generally is well provided with apparatus and men. Recent loss of life has been very small.

Electricity has been shown to be by far the most frequent cause of ignition. The common belief that a trolley circuit will not start a fire has been disproved. The number of mine fires in which every type of electrical equipment has been involved as a cause, demonstrates the need of carefully installing and inspecting electrical equipment.

The number of fires which have started between regular working shifts shows the value of fire patrols during the time when no work is being done.

A survey of fire hazards and a detailed plan of fire fighting in each mine is recommended.

Probably the most essential factor in the handling of a mine fire is mechanical control of ventilation; hence every mine, metal as well as coal, should have a mechanically operated fan and a well systematized coursing and control of air currents.

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